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The Origins and Design of Nabataean Water-Supply Systems

In the late first century BC, Diodorus of Sicily, probably quoting the third-century historian Hieronymos of Kardia, described the Nabataeans in this romantic fashion:

> They live in the open air, claiming as native land a wilderness that has neither rivers nor abundant springs from which it is possible for a hostile army to obtain water. It is their custom neither to plant grain, set out any fruit-bearing tree, use wine, nor construct any house; and if anyone is found acting contrary to this, death is his penalty. They follow this custom because they believe that those who possess these things are, in order to retain the use of them, easily compelled by the powerful to do their bidding. Some of them raise camels, others sheep, pasturing them in the desert. While there are many Arabian tribes that use the desert as pasture, the Nabataeans far surpass the others in wealth although they are not much more than ten thousand in number, for not a few of them are accustomed to bring down to the sea frankincense and myrrh and the most valuable kinds of spices, which they procure from those who convey them from what is called Arabia Eudaemon. They are exceptionally fond of freedom, and whenever a strong force of enemies comes near, they take refuge in the desert, using this as a fortress; for it lacks water and cannot be crossed by others, but to them alone it furnishes safety, since they have prepared subterranean reservoirs lined with plaster... After filling these cisterns with rain water, they close the openings, making them even with the rest of the ground, and they leave signs that are known to themselves but are unrecognizable to others... They use as food flesh and milk and those plants that are suitable for this purpose. (19.94.2-10)[1]

This valuable passage, along with related sections not quoted here, probably reflects fairly accurately the character of early Nabataean society and the resources upon which it depended.[2] The early Nabataeans were wandering pastoralists who lived largely off the land and shifted their flocks of sheep, goats and camels from place to place depending on season and the conditions of the pasturage. The water that sustained them in the desert was for the most part runoff from the meager precipitation that fell in the winter months and was stored in plastered cisterns cut in the bedrock. There were no rivers in Edom, always the Nabataean heartland, and the infrequent springs seldom flowed in significant volume; often they were no more than seepages. Except for a few small areas around the peaks of the mountains towering over the eastern slope of Wādī ʻArabah, precipitation is less than 100 mm per year, and for most of Edom it ranges between 25 and 75 mm. Because of the strong, constant sunshine and the low humidity, pan evaporation– the rate of evaporation of exposed bodies of water– ranges between 3000 and 4000 mm per year.[3]

Nevertheless, this dramatic, isolated desert landscape carried–according to Diodorus' source–a very significant population. We do not have to accept the figure of ten thousand literally to understand that the Nabataeans were making the best of their resources. Although seemingly barren to North American eyes, the desert of what is now southern Jordan and northern Saudi Arabia had other resources for its ancient inhabitants besides precipitation. There were edible flora and fauna, clay for ceramics, and bitumen from the Dead Sea–much sought after by the Egyptians for embalming.[4] But even more important was

[1] Quoted from R. M. Geer, *Diodorus of Sicily*, vol. 10. Cambridge, MA: Harvard Universiry Press, 1954, pp. 87-91.

[2] On early Nabataean history, see P. C. Hammond, *The Nabataeans: Their History and Culture*. Gothenburg: P. Åström, 1973; M. Lindner, ed., *Petra und das Königreich der Nabataer,* 4th ed. Munich: Delp, 1983; A. Negev, 'The Early Beginnings of the Nabataean Realm.' *PEQ* 108 (1976) 125-133; *idem, Nabataean Archaeology Today.* New York: New York University Press, 1986.

[3] Rainfall and evaporation statistics can be found in *National Water Master Plan of Jordan.* Amman: Natural Resources Authority, 1977.

[4] For trade goods see P. C. Hammond, 'The Nabataean Bitumen Industry at the Dead Sea.' *BA* 22 (1959) 40-48; D. J. Johnson, *Nabataean Trade: Intensification and Culture Change.* Ph.D. diss. University of Utah, 1987. There is a good discussion of native flora in M. Evenari, L. Shanon and N. H. Tadmor, *The Negev. The Challenge of a Desert.* 2nd ed. Cambridge, MA: Harvard, 1982, pp. 229-323

the location of Edom on the land bridge that linked the Red Sea and the Arabian peninsula on the south with the Ḥawrān and the Decapolis on the north, the Persian Arabian Gulf on the east with the Levantine coast of the Mediterranean on the west. Even in the 1990s the modern Hashemite Kingdom of Jordan both profits and suffers from its location at the crossroads of the Middle East. Already in the early centuries of the Nabataean presence in Edom, Nabataean merchants were bringing spices and aromatic resins to Mediterranean ports by caravan, and Nabataean camel drivers and guides were conducting and–one suspects–fleecing caravans that crossed their lands carrying goods to the hungry markets of the Mediterranean world.[5]

What does all this have to do with Nabataean hydraulic technology? Consideration of the information provided by Diodorus allows reconstruction of at least the basic outlines of the early Nabataean society and economy, and, in hostile environments, the interaction between technology and society is particularly keen and often easier to document than in less marginal areas of the world. Before examining the technology of water supply in the Nabataean culture, one more ancient literary source must be considered, the historian Strabo, writing in the late first century BC or the early first AD.

> The Nabataeans are a sensible people, and they are so much inclined to acquire possessions that they publicly fine anyone who has diminished his possessions and also confer honours on anyone who has increased them. Since they have but few slaves, they are served by their kinsfolk for the most part, or by one another..., or even by their kings. They prepare common meals together in groups of thirteen persons, and they have two girl-singers for each banquet. The king holds many drinking-bouts in magnificent style, but no one drinks more than eleven cups of wine, each time using a different golden cup. The king...often renders an account of his kingship in the popular assembly; and sometimes his mode of life is examined. Their homes, through the use of stone, are costly; but on account of peace, the cities are not walled. Most of the country is well supplied with fruits except the olive; they use sesame oil instead. The sheep are white-fleeced and the oxen are large, but the country produces no horses. Camels afford the service they require instead of horses... Some items are imported completely from other countries, but others only in part, especially in the case of native products, such as gold and silver and most of the aromatics, whereas copper and iron, purple garments, styrax, crocus, costaria, embossed metalwork, paintings, and moulded images are not produced locally. (16.4.26)[6]

The contrast between the hedonistic, settled Nabataeans described by Strabo and the lean, foxy nomads described by Diodorus has provoked frequent comment.[7] What we see, of course, is a neat summary of the changes that overtook Nabataean society between the third and the first century BC: monarchy (although remarkably populist in tone), a sort of settled urbanism with elaborate stone houses, agriculture (including fruit trees and vineyards), herds of animals–including carefully bred and well-fed cattle, and luxurious possessions associated with sophisticated manufacture and long-distance trade. The technology of water supply, unfortunately, is not mentioned, but implicit in the overall picture are more sophisticated structures and techniques than the rock-cut cisterns mentioned by Diodorus. How were these materialistic wine-bibbers and flute girls, their homes, flocks and fields supplied with water in an environment just as arid in the first century BC as it had been in the third and as it is today?[8] In part, the increased production of water resulted from the adaptation or more intensive application of water-harvesting techniques that went back at least to the Iron Age Edomite culture. But, in part, the higher standard of living also resulted from the introduction of new techniques from the Hellenistic world. We can only touch here on the contentious topic of why the Nabataeans so enthusiastically embraced a settled life at all. It is likely that sedentarization in this case evolved or was intentionally fostered to provide an alternative economic system to the caravan trade, which seems to have been increasingly diverted from Nabataean to Egyptian or Syrian routes in the first century BC.[9]

Although meager in amount and very localized in occurrence, precipitation does fall reliably in the desert

[5] For the Red Sea trade and Nabataean caravan activity, see J. W. Eadie, 'Strategies of Economic Development in the Roman East.' Pp. 113-120 in D. H. French and C. S. Lightfoot, eds., *The Eastern Frontier of the Roman Empire*. Oxford: BAR, 1989; L. Casson, *The Periplus Maris Erythraei*. Princeton: Princeton University Press, 1989, pp. 9, 61-63, 143-144.

[6] H. L. Jones, *Geography of Strabo*, vol. 7. Cambridge, MA: Harvard, 1930, pp. 367-369.

[7] A. Negev, 'The Nabataeans and the Provincia Arabia.' Pp. 520-686 in H. Temporini and W. Haase, *ANRW* II.8 (1977) 523 ff.; G. Bowersock, *Roman Arabia*. Cambridge, MA: Harvard, 1983, p. 12.

[8] For the general lack of climatic change since the Neolithic or Early Bronze Age, see N. Shehadeh, 'The Climate of Jordan in the Past and Present.' Pp. 25-37 in A. Hadidi, ed., *Studies in the History and Archaeology of Jordan*, II. Amman: Department of Antiquities, 1985; R. Rubin, 'The Debate over Climatic Changes in the Negev, Fourth-Seventh Centuries C.E.' *PEQ* 121 (1989) 71-78; also, W. C. Lowdermilk, 'The Use of Flood-Waters by the Nabataeans and Byzantines.' *IEJ* 4 (1954) 50-51.

[9] Sedentarization is discussed in Bowersock (above, n. 7) 64; *idem*, 'Nabataeans and Romans in the Wadi Sirhan.' Pp. 133-136 in A. M. Abdalla, *et al.*, eds., *Studies in the History of Arabia*, 2. Riyad: King Saud Press, 1984; S. Hart, 'Some Preliminary Thoughts on Settlement in Southern Jordan,' *Levant* 18 (1986) 51-58; D. Graf, 'Nabataean Settlements and Roman Occupation in Arabia Petraea'. Pp. 253-260 in *Studies in the History and Archaeology of Jordan*, IV. Amman: Derpartment of Antiquities, 1992; O. S. LaBianca, *Hesban I: Sedentarization and Nomadization*. Berrien Springs, MI: Andrews University, 1991; S. T. Parker, 'Peasants, Pastoralists, and *Pax Romana:* A Different View.' *BASOR* 265 (1987) 35-51.

every year when averaged out over the large catchment areas individual Nabataean tribal groups and settlements controlled. The secret of survival was the knowledge of how to harvest this precipitation. The most obvious techniques had been discovered by the Iron Age and put to work in many of the arid areas of the ancient Near East.[10] The terracing of hillsides is perhaps the most spectacular and visible of these early methods: heavy stone walls built across the slope of a hill captured both runoff water and the particles of earth it carried. The reservoir of soil gathered and protected in this fashion served in turn as a sponge to hold moisture to sustain the crops planted on the level surface created. In a variation on this technique, walls were built across wadis, dry stream beds that carried the concentrated runoff from a catchment area. Although vulnerable to damage, walls and fields in such a location were more likely to receive significant runoff and alluvial soil than the terraces on the slopes above. Because the principle involved was so obvious, the construction techniques relatively simple, and the need for maintenance constant, ancient terraces and wadi barriers in the Near East have often remained in use for long periods of time and lost their original appearance. But occasionally, single period sites provide a glimpse of their use in the Bronze or Iron Age, for example at the Early Bronze Age site of Tall al-Ḥandaqūq.[11]

A variation on the wadi barrier, the containment dam designed to trap and hold a pool of water, was attempted in the Near East as early as the Early Bronze Age, but seldom with much success. The barrier wall had to be capable all at once of withstanding the shock of the water's sudden arrival, its erosive action as it poured over the spillway, and the weight of the standing pool. The barrier and reservoir walls also had to be impermeable or at least highly resistant to the percolation of the water they retained. In antiquity, as today, there have been spectacular failures of containment dams, as at the Old Kingdom Wādī Garawi dam.[12] Even when structurally successful, containment dams provided a pool of water that was subject to the enormous evaporation typical of the desert regions, and the quality of the water would have been low because of pollution by bird and animal droppings and by plant, insect and animal life in the pool itself. Nevertheless, erosion of the soft sandstone typical of Edom has produced natural pools that have been used with little or no human alteration from antiquity to the present.[13]

From the Early Bronze Age on, cisterns have been the preferred method for capturing and storing water to be used for drinking. The entry of water was controlled, and the captured water was protected from evaporation and pollution. Hand in hand with advances in cistern design, the archaeological record shows progress in the creation of plasters resistant to the percolation and erosive effect of the water. By the Iron Age, the Edomites had settled on the rock-cut bottle cistern as appropriate to their needs, well illustrated by examples at the Edomite settlement on Umm al-Biyara at Petra (FIG. 1).[14] This type of cistern remained in use among the early Nabataeans and is described by Diodorus' source:

> They have prepared subterranean cisterns lined with plaster... As the earth in some places is...of soft stone, they make great excavations in it, the mouths of which they make very small, but by constantly increasing the width as they dig deeper, they finally make them of such a size that they can be one plethron [27 metres! ed.] wide. (19.94.7)[15]

Although the Edomite cisterns are much smaller in size, usually shaped like a bottle with small neck and three to four metres in greatest diameter, they served

1. Umm al-Biyāra, Petra: Rock-cut bottle cistern (Photo: Oleson).

[10] Studies of Nabataean water-supply technology can be found in Evenari *et al.* (above n. 4); J. P. Oleson and J. W. Eadie, 'The Water-Supply Systems of Nabataean and Roman Ḥumayma.' *BASOR* 262 (1986) 49-76; M. Lindner, 'Die Wasserversorgung einer antiker Stadt—Petra.' Pp. 196-201 in G. Garbrecht, *Der Wasserversorgung antiker Städte.* Mainz: von Zabern, 1987; Z. al-Muheisen, *L'alimentation en eau de Petra.* Diss. Sorbonne. Paris: 1983.

[11] J. Mabry, 'Investigations at Tell el-Handaquq, Jordan (1987-88).' *ADAJ* 33 (1989) 59-95. For terraces, see also Z. Ron, 'Agricultural Terraces in the Judean Mountains.' *IEJ* 16 (1966) 33-49; T. E. Levy and D. Alon, 'Settlement Patterns along the Nahal Beersheva-Lower Nahal Besor. Models of Subsistence in the Northern Negev.' Pp. 45-138 in T. E. Levy, *Shiqmim*, I. Oxford: BAR, 1987, esp. pp. 55-59.

[12] For the Wadi Garawi dam, see G. Garbrecht, 'Geschichtliche Talsperren im östlichen Mittelmeerraum,' *Leichtweiss-Institut für Wasserbau, Mitteilungen* 82 (1984) 1-23; R. L. Bowen, Jr. and F. P. Albright, eds., Archaeological Discoveries in South Arabia. Baltimore: The Johns Hopkins University Press, 1958, pp. 62-81; M. Lindner, 'Nabatäische Talsperren.' Pp. 147-174 in G. Garbrecht, *Historische Talsperren.* Stuttgart: Wittwer, 1987; R. Rubin, 'Water Conservation Methods in Israel's Negev Desert in Late Antiquity.' *Journal of Historical Geography* 14 (1988) 229-244.

[13] There is a spectacular series of natural and adapted pools at Muqawwar, east of Ḥumayma; see W. Jobling, 'Aqaba-Ma'an Archaeological and Epigraphical Survey.' Pp. 16-24 in D. Homès-Fredericq and J. B. Hennessy, *Archaeology of Jordan,* II: *Field Reports, Surveys, and Sites.* Akkadica, Supp. 7. Leuven: Peeters, 1989.

[14] For early cisterns, see I. Browning, *Petra.* rev. ed. London: Chatto & Windus, 1982, p. 176; G. and A. Horsfield, 'Sela-Petra, The rock of Edom and Nabatene.' *QDAP* 7 (1938) 1-42.

[15] Geer (above, n. 1) 88-89.

their intended purpose well. They were cut in the rock close to the focus of a natural catchment and provided with small feeder channels to lead the water into the draw-hole or a special intake hole. Their interiors were lined with a hard, sandy white plaster.

The infrequent, and thus all the more welcome, springs and seepages of Edom, for the most part found among the strata exposed by the ash-Sharāh escarpment or the Dead Sea rift, must always have been a focus of human activity. Because of the constant use of these sites from the Palaeolithic to the present, their original appearance, and the earliest methods of enhancing or capturing their flow cannot be documented. The most appropriate methods, however, are obvious, and probably were in use by at least the Early Bronze Age. The original muddy pools would have been cleared out, and eventually lined with stone, and conduits provided to carry the overflow to adjacent artificial pools or fields. The *qaṭṭār*, or site where water seeps from an exposed aquifer, is exploited by trimming back the original face and by cutting runnels and basins to concentrate and collect the water (FIG. 2).[16]

These were the techniques available to the early Nabataeans as they moved into the southern desert and Edom–possibly from northwestern Arabia and possibly around the fifth century BC.[17] Judging from the rapidity

2. Qaṭṭār in Wādī Qaṭṭār ad-Dayr, Petra (Photo: Oleson).

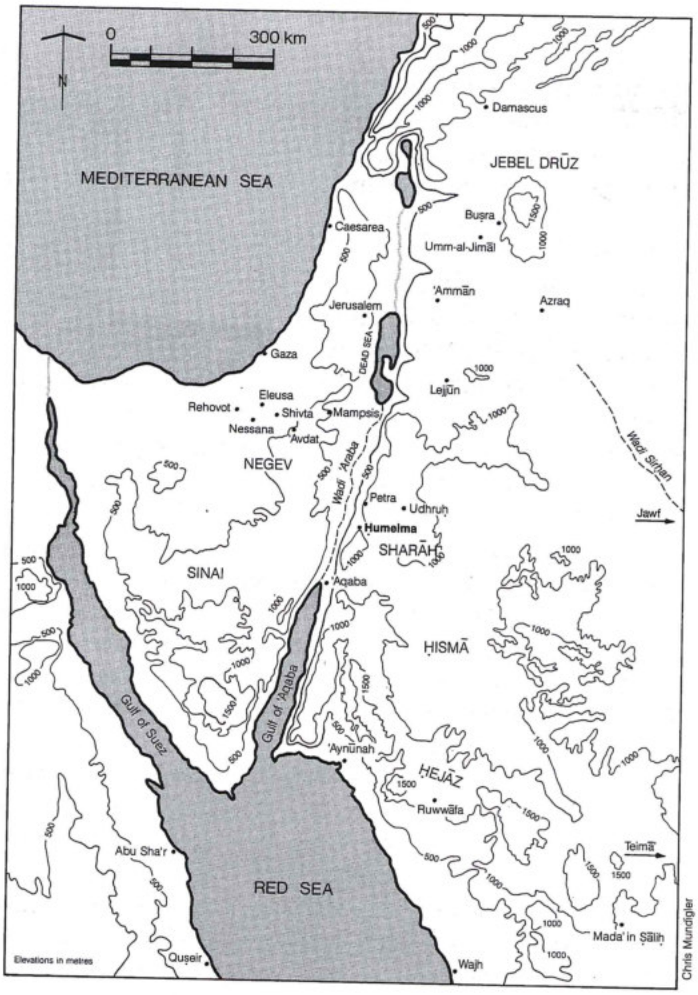
with which they occupied their new territory, they undoubtedly already knew or quickly learned the appropriate methods of harvesting the scanty desert precipitation. But in the course of the second and first centuries BC new techniques appeared, probably first in response to a growing population and more frequent transit through the desert, then in response to the shift to a more settled, agricultural economy. Since many of these techniques remained in use through the Byzantine period throughout the area occupied by Nabataean communities–from the Ḥawrān on the north to the Ḥijāz on the south, and west across an-Naqab (the Negeb) to the Mediterranean coast, it is very difficult to document the precise time and place of their introduction (FIG. 3). Nevertheless, recent excavations at Ḥumayma, ancient Auara, a Nabataean settlement in southern Jordan, suggest that the first century BC was a period of particularly rapid innovation and that Nabataean needs governed the process.[18]

These new and revised techniques of water management can be grouped under the three headings of collection, transport and storage. For most of the desert areas of the Nabataean kingdom, collection of water was the most critical consideration, and–although simple in principle–required careful consideration. One characteristic of a desert landscape is the absence of a heavy ground cover of plants and the humus on which they feed and to which they contribute. Except where it falls on pure drift sand, much of the precipitation in a desert runs off the surface unimpeded and quickly collects in short-lived torrents that fill the wadis and grow in force until they empty into mud flats or cross absorbent geological deposits. The runoff resulting from even minor rain showers is even more impressive in the sandstone mountains of the Petra region, for example. In collecting runoff water, it was important to strike a balance between too large a catchment, which might yield a torrent very difficult to control, and one too small, which might be missed altogether by localized desert rain storms. The potential for excess flow was less important in situations where the water was to be conducted across sturdy wadi barriers to moisten agricultural soil than where it was

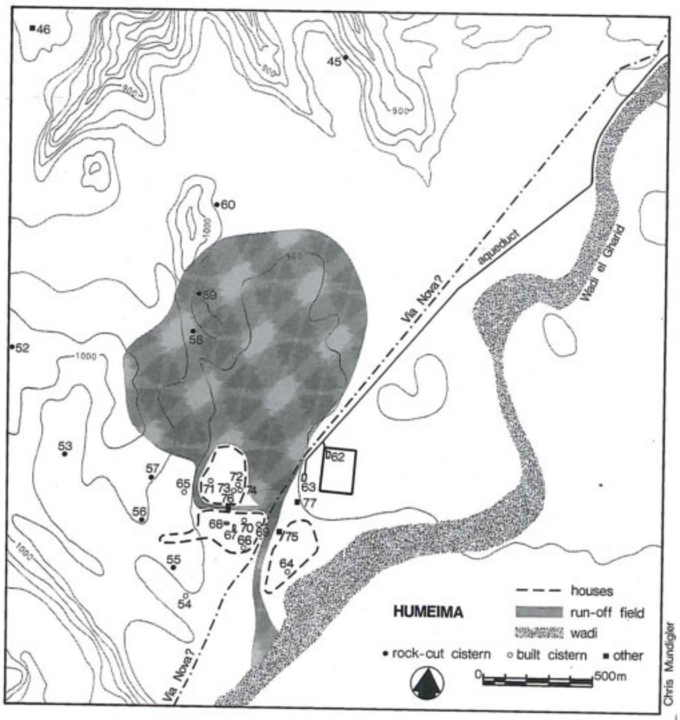
[16] There is a *qaṭṭār* at Muqawwar; see Jobling (above n. 13). There is another well preserved example at Petra, in Wādī Qaṭṭār ad-Dayr (here, FIG. 2).

[17] On the origins of the Nabataeans, see F. Altheim and R. Stiehl, *Die Araber in der Alten Welt,* 1: *Bis zum Beginn der Kaiserzeit.* Berlin: Walter De Gruyter, 1963, pp. 31-39; A. Negev, 'The Early Beginnings of the Nabataean Realm.' *PEQ* 108 (1976) 125-133; H. P. Roschinski, 'Geschichte der Nabatäer.' *Bonner Jarhbücher* 180 (1980) 129-154; and now the interesting sythesis presented by D. Graf, 'Arabia during Achaemenid Times.' Pp. 131-48 in H. Sancisi-Weerdenburg and A. Kuhrt, eds. *Achaemenid History,* IV: *Centre and Periphery.* Leiden: Nederlands Instituut voor het Nabije Oosten, 1990.

[18] The author has been directing survey and excavation at Ḥumayma since 1986. Selected publications include J. P. Oleson, 'The Ḥumayma Hydraulic Survey: Preliminary Report of the 1986 Season.' *ADAJ* 30 (1986) 253-260; *idem*, 'Technology and Society in Ancient Edom.' *Transactions of the Royal Society of Canada* ser. 5, vol. 2: (1987) 163-174; *idem*, 'The Ḥumayma Hydraulic Survey: Preliminary Report of the 1987 Season.' *ADAJ* 32 (1988) 157-169; *idem*, 'The Ḥumeima Hydraulic Survey: Preliminary Report of the 1989 Season.' *ADAJ* 34 (1990) 285-311; *idem*, 'Aqueducts, Cisterns, and the Strategy of Water Supply at Nabataean and Roman Auara (Jordan).' Pp. 45-62 in A. Trevor Hodge ed., *Future Currents in Aqueduct Studies*. Leeds: Francis Cairns, 1991; *idem*, 'The Water-Supply System of Ancient Auara: Preliminary Results of the Ḥumeima Hydraulic Survey.' Pp. 269-75 in *Studies in the History and Archaeology of Jordan*, IV. Amman: Department of Antiquities, 1992; J. P. Oleson, K. 'Amr and R. Schick. 'The Ḥumeima Excavation Project: Preliminary Report of the 1991 Season.' *Echos du Monde Classique* 11 (1992) 137-169; J. P. Oleson, D. Graf and J. Eadie, 'Ḥumayma.' Pp. 270-274 in D. Homès-Fredericq and J. B. Hennessy, eds., *Archaeology of Jordan,* II: *Field Reports*. Akkadica, Supp. 7. Leuven: Peeters, 1989; J. P. Oleson, K. 'Amr, R. Schick, R. M. Foote and J. Somogyi-Csizmazia, 'The Ḥumeima Excavation Project: Preliminary Report of the 1991-1992 Seasons.' *ADAJ* 37 (1993) 461-502; *idem*, 'The Ḥumeima Excavation Project, Jordan: Preliminary Report of the 1992 Season.' *Echos du Monde Classique* 12 (1993) 123-158.



3. Location of Ḥumayma in Nabataea.



4. Plan of Ḥumayma.

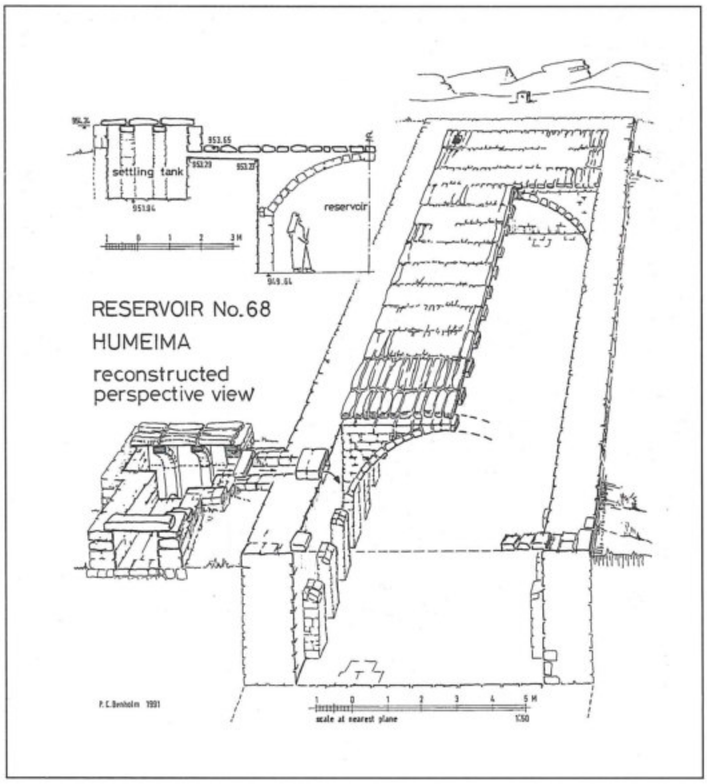
meant to fill cisterns close to habitation areas, particularly where the cisterns were built of blocks rather than cut in the bedrock.[19]

The settlement of Ḥumayma, ancient Auara, is interesting in this regard. According to the first-century (or possibly fourth-century) historian Euranios, Auara was founded in the 80s BC by King Aretas III (87-62 BC, possibly before his accession to the throne) on the caravan route that later became the *Via Nova Traiana*, in what is now Jordan's southern desert.[20] The king probably wanted both to facilitate the caravan trade and to foster exploitation of the fertile loessal soils on the adjacent plain, but there is no obvious reason for the precise location of the settlement other than the presence of an excellent water-catchment field to supply the cisterns on which Auara was to depend (shaded in on FIG. 4). This field, approximately one square kilometer in area, slopes gently (at approximately two percent) from north to south towards a natural outlet approximately 50 metres across, framed by low rises. If the whole field received the 80 mm of rain which the region averages through the year, and even it as much as fifty percent of it were absorbed, 40,000 cubic metres would still run through this gap–enough water to sustain a population of 11,000 for a year, if it could be stored.[21] In fact, King Aretas intended the settlement to depend on two large public cisterns built as a pair 50 m west of the gap–close enough to be filled through collection channels, but out of harm's way. Each cistern had a capacity of approximately 460 cubic metres and together they held more than enough water to sustain, for example, a population of 250 humans, or 100 humans and 1100 goats (FIG. 4, no. 67 and 68; FIG. 5). Of course the runoff field might well not yield 40,000 cubic metres of water every year, but the subsequent history of Auara shows that the safety margin was sufficient. During the 800 years of the settlement's existence, more than 30 houses were built on the low slopes surrounding these public cisterns. For

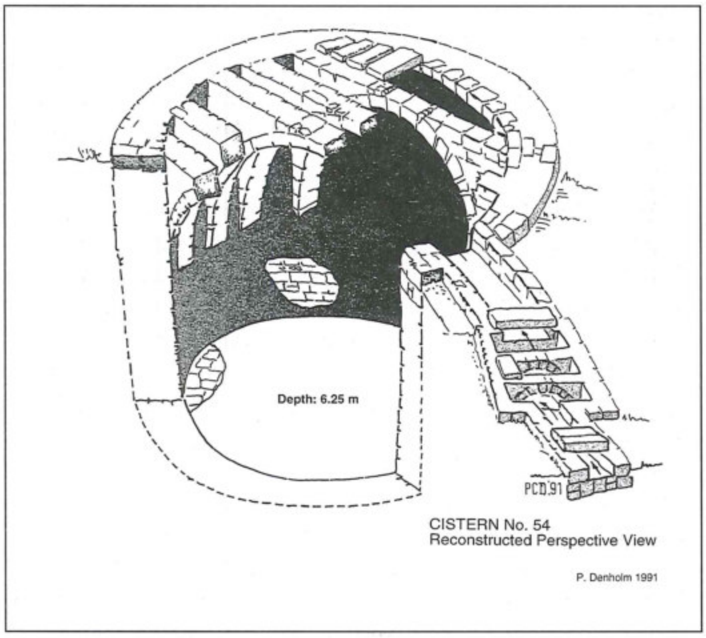
19 Evenari *et al.* (above, n. 4) 99-119, 179-189.

20 The fragments of Uranius are assembled in F. Jacoby, *Die Fragmente der griechischen Historiker,* III C. Leiden: Brill, 1958, pp. 339-344; on this enigmatic author, see J. M. I. West, 'Uranius.' *HSCP* 78 (1974) 282-284. The best treatments of the Nabataean history of the region around Ḥumayma are D. Graf, 'The Nabataeans and the Hisma: In the Steps of Glueck and Beyond.' Pp. 647-664 in C. L. Meyers and M. O'Connor, eds., *The Word of the Lord Shall Go Forth: Essays in Honor of David Noel Freedman*. Winona Lake: Eisenbrauns, 1983; *idem*, 'Qura 'Arabiyya and Provincia Arabia.' Pp. 171-203 in *Géographie historique au Proche-Orient, Notes et monographes techniques,* no. 23. Paris: CNRS, 1988.

21 For statistics on human consumption see S. Helms, 'Paleo-Bedouin and Transmigrant Urbanism.' Pp. 97-113 in A. Hadidi, ed., *Studies in the History and Archaeology of Jordan,* I. Amman: Department of Antiquities, 1982; *idem, Jawa. Lost City of the Black Desert.* Ithaca: Cornell, 1981, p. 189.

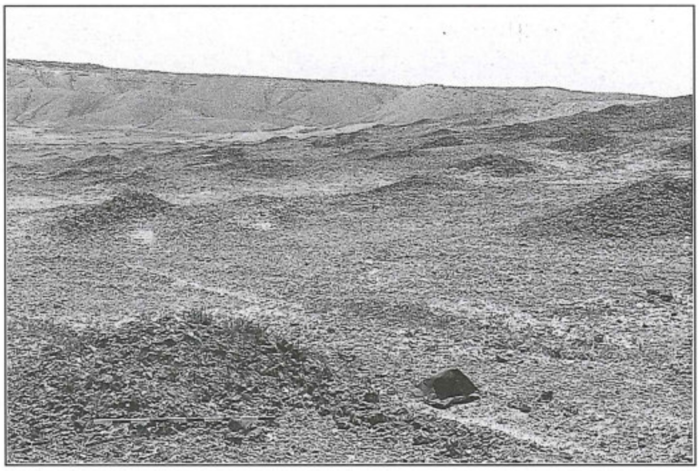


5. Reconstruction of public cistern no. 68, Ḥumayma.



6. Reconstruction of Private Cistern no. 54, Ḥumayma.

the sake of convenience, some of them tapped the same runoff course to fill smaller, circular cisterns below their private courtyards (FIG. 6). Many of these cisterns are



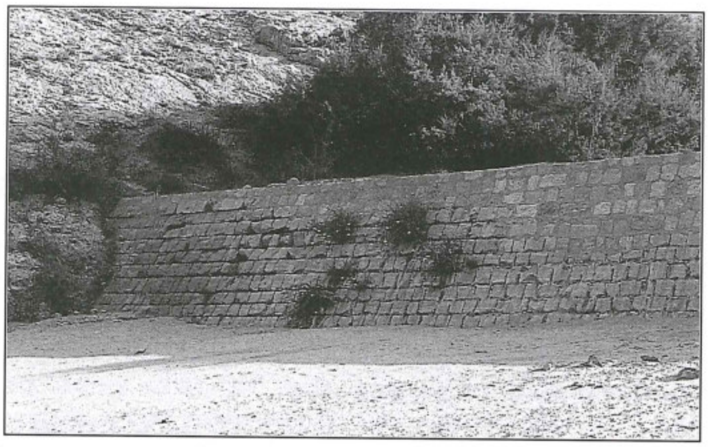
7. Stone mounds facilitating runoff, Shivta (Photo: Oleson).

still in use today, filled by the sparse but predictable desert rainfall even though maintenance of the catchment channels seems haphazard. As far as we can tell, the adjacent wadi bed, which drains approximately 200 square kilometres of the Auara catchment, was left almost completely alone, probably because its flow was too violent to allow easy diversion.

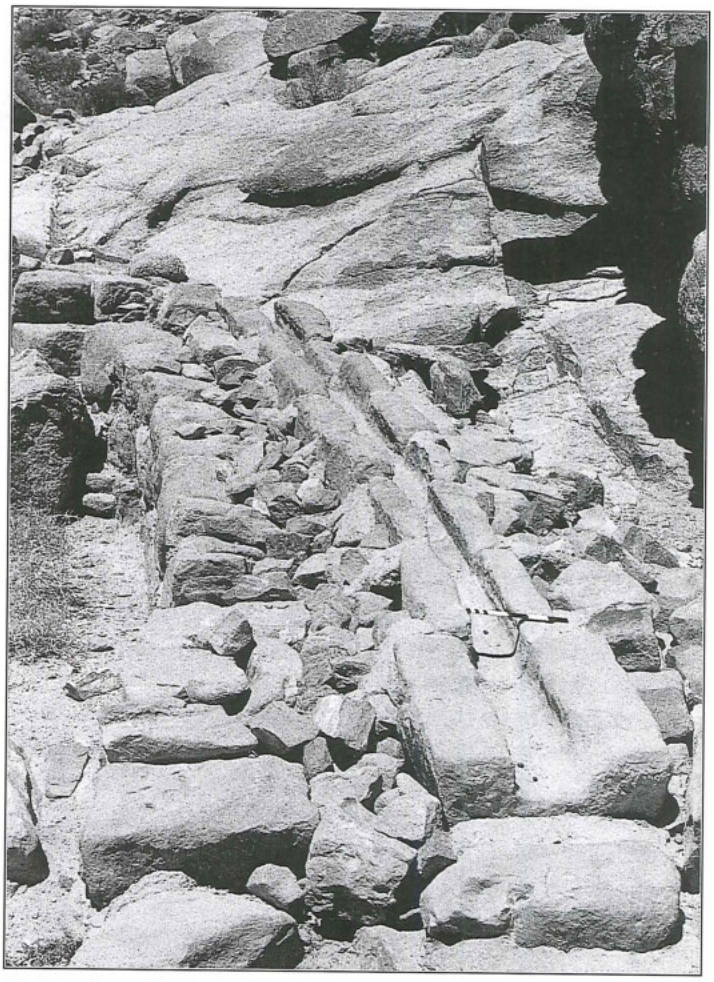
Catchment areas could be adapted to human needs by building containment walls or cutting channels at the edges of a slope to salvage water or to divert it towards a small cistern opening. Features of this type were relatively easy to arrange on bedrock slopes, and throughout the Ḥisma, particularly around Ḥumayma, many of them still function today as they were designed originally. The enhancement of runoff on earth slopes, however, required more planning and greater maintenance. Earth conduits have survived at some sites, such as Shivta in an-Naqab.[22] Everywhere around the late Nabataean cities of an-Naqab, the gravelly slopes are covered with man-made patterns formed by piling field stones in regular heaps or lines (FIG. 7).[23] These laborously-constructed heaps probably were intended to serve two purposes. Removal of the surface stones allowed the soil to crust over almost immediately after it was moistened by rain and thus fostered unimpeded runoff from the slopes, increasing the yield of water. The absence of small stones probably also fostered the gradual transport of fresh soil particles to terraced fields on the slopes or in the wadis below. Erosion and deflation of the exposed soil meant that continued clearing of the gaps was essential, and today in most cases the exposed surface soil has disappeared. So far it has not been possible to date these features precisely, but they may well have appeared around the Nabataean cities of an-Naqab in the first cen-

22 For Shivta, see Y. Kedar, 'Ancient Agriculture at Shivtah in the Negev.' *IEJ* 7 (1957) 178-189; A. Segal, 'Shivta—A Byzantine Town in the Negev Desert.' *JSAH* 44 (1985) 317-28; Evenari *et al.* (above, n. 4) 103, FIG. 69.

23 These mounds used to be called *tulailat al-'inab* ("grape mounds") on the assumption that they were heaped up to protect vines, an idea debunked—in my opinion—by Evenari *et al.* (above, n. 4) 126-147. See also K. C. Gutwein, *Third Palestine: A Regional Study in Byzantine Urbanization*. Washington D.C., Univesity Press of America, 1981, 77.



8. Nabataean dam, Mampsis (Photo: Oleson).



9. Aqueduct, 'Ayn ash-Shallālah, Wādī Ramm (Photo: Oleson).

tury BC or AD, the time of their initial flowering, and remained in use through the Byzantine period. Catchment fields enhanced in this manner are very rare in southern Jordan, probably because of differences in local geology and topography. At most sites in this region large areas of exposed bedrock form excellent natural runoff areas, and there are extensive deposits of loess in the plains, formed during the Pleistocene period.[24]

Another hydraulic management technique typical of Nabataean settlements is the application of wadi barriers to divert excess water flow into channels that carried it to fields above the wadi bed proper. This arrangement both expanded the area of watered fields and avoided the loss of soil and moisture that resulted when a wadi in spate breached a barrier wall. The technique may have been borrowed from the Nile Valley, where it had been in use for millennia as a technique for irrigating fields above the level of the Nile flood.[25]

Containment dams represent a different approach altogether. Small ones built across steep-walled gullies to form a type of cistern are common in the sandstone topography of Petra and other Nabataean settlements in southern Jordan, but these dams–really a type of free-standing cistern wall–do not entail the same engineering problems as larger containment dams. Perhaps best known of these large dams are three at Mampsis/Kurnub in an-Naqab which barred the main wadi and created pools holding 10,000 cubic metres of water. Their date is still not certain, but an origin in the first or second century has been proposed on historical grounds.[26] The containment walls, built of mortared blocks, had vertical faces upstream and sloping walls downstream for buttressing (FIG. 8). Recent rebuilding has concealed the original spillway arrangement. A smaller dam (10.7 m long, 4.4 m thick) at Ḥumayma/Auara had a narrow enough span and was thick enough that buttressing was not necessary.[27] In this case, the spillway, always the most vulnerable point on a containment dam, was cut in the bedrock to one side of the mortared masonry wall. It contained a reservoir of approximately 1400 cubic metres, made accessible by steps cut in the steep rock wall of the canyon at one side. The pools behind the dams at both Kurnub and Auara are filled to the brim with silt and sand, reminding us that constant maintenance would

24 There is one clear example at Ḥumayma; see Oleson (above, n. 18) 1986, PL. 46.2.

25 There are excellent discussions of the wadi barriers used in an-Naqab, in M. Evenari and D. Koller, 'Ancient Masters of the Desert.' *Scientific American* 194.4 (1956) 39-45; also in Evenari *et al.* (above, n. 4) 95-120, 179-190. On Egyptian technique, see R. J. Forbes, *Studies in Ancient Technology,* vol. 2. Leiden: Brill, 1965, pp. 25-32.

26 See A. Negev, *The Architecture of Mampsis, Final Report, I: The Middle and Late Nabataean Periods.* Jerusalem: Hebrew Univesity, 1988, pp. 6-7, 17-18 and the references cited there. For Nabataean and later dams in general, see the citations in note 12 above, along with B. De Vries, 'The el-Lejjun Water System.' Pp. 399-428 in S. T. Parker, ed., *The Roman Frontier in Central Jordan,* pt. i. Oxford: BAR, 1987; P. Parr, 'La date du barrage du Siq à Petra.' *RB* 74 (1967) 45-49. W. Jobling, 'Prospection archéologique et épigraphique dans la région d''Aqaba-Ma'an.' *Syria* 60 (1983) 317-323, reports on some interesting small dams or wadi barriers near Ḥumayma. For parallel techniques in North Africa, see P. Trousset, 'Les oasis présahariennes dans l'antiquité: Portage de l'eau et division du temps.' *Antiquités africaines* 22 (1986) 163-193.

27 J. P. Oleson, 'Eine nabatäische Talsperre in der Nähe von Ḥumeima (das antike Auara) in Jordanien.' Pp. 65-71 in G. Garbrecht, ed., *Historische Talsperren,* 2. Stuttgart: Wittwer, 1991.

have been necessary to keep this sort of structure functioning properly. The famous dam across the upstream end of the Sīq at Petra was designed simply to divert the water through a tunnel, leaving the original wadi bed free as a road.[28]

Enhancement, diversion or containment of runoff or spring water often had to be combined with transport of the water to a location more convenient for its use or storage. Prof. Jobling has found some low, block-built barrier walls in the Ḥisma that created small pools of runoff water in sandstone gullies and directed the overflow into small channels cut into the bedrock that conducted the water to cisterns nearby.[29] Short stretches of conduits cut into sandstone blocks were also used in Nabataean settlements to guide water from roofs or paving into cisterns. This type of conduit block, consisting of a channel usually around 12 cm wide and 15 cm deep cut into a block of local sandstone, marl or limestone 60 to 90 cm long, is the typical water channel in the area of the Nabataean kingdom from at least the first century BC through the Byzantine period.[30]

Conduits built in this manner were typically associated with spring water, which was highly valued for its quality and which was more likely than other sources to be found in a location inappropriate for a cistern or inconvenient for human habitation. Conduits have been found at virtually all the springs in the region, varying in preserved or conjectured length from several metres to a colossal 27 kilometres for the aqueduct serving Ḥumayma.[31] The conduit that carried the water from 'Ayn Mūsā to Petra was approximately 6 kilometres long. The conduit carrying the water from 'Ayn ash-Shallālah in Wādī Ramm to the adjacent sanctuary was 1.5 km long (FIG. 9). All of these conduits fed reservoirs along their courses and at their termination and they share technical characteristics peculiar to the Nabataean examples. In the first place, the channel size and design flow are far below those of the typical Hellenistic or Roman aqueduct. While the water channel of the Aqua Marcia was approximately one metre wide and deep, and its flow 187,600 cubic metres per day, the channel of the main aqueduct serving Petra was 15 cm square and had a maximum flow of no more than 500 cubic metres per day. The long conduit serving Ḥumayma had a channel 12 by 15 cm, and could have discharged at most 148.6 cubic metres per day.[32] These capacities, of course, were designed to correspond to the resources available, which were far less abundant than the springs and rivers of central Italy. The Ḥumayma aqueduct had two branch lines fed by three springs with a maximum total flow at present of only 53 cubic metres per day. Nabataean water conduits also differed from Roman aqueducts in their typical ground-level course. They did not tunnel through the bedrock or soil for the first part of the run, then rise up on arches to maintain as much of the head as possible at the point of use. The date of the introduction to this region of the *qanat*, or subterranean conduit excavated by means of the chain of access shafts, is still uncertain. It may belong only to the Islamic period, but in any case, it was rarely used in Arabia Petraea. There are examples at Yotvata, Qaṣr al-Mushāsh, and Udhruḥ.[33]

10. Ḥumayma aqueduct (Photo: Oleson).

Some well preserved stretches of a typical ground-level conduit were excavated along the Ḥumayma aqueduct (FIG. 10).[34] The conduit blocks were laid end-to-end in a bedding of crumbly mortar and fist-sized rubble, framed by heavy, roughly trimmed blocks and boulders. A course of small stones set in plaster ran along either side of the channel to support heavy, partly-trimmed cover slabs. A ground-level channel of this type had to be roofed, in order to prevent obstruction by falling rocks or blowing sand, evaporation, the entry of pollutants, and unauthorized diversion of the water. Evidence was found that in the last years of its functioning, portions of the conduit leading to Ḥumayma were left uncovered, allowing algae or grass to grow in the channel. The tiny stalks attracted calcium carbonate deposits, which grew

28 Parr (above, n. 26); al-Muheisen (above, n. 10).

29 Jobling (above, n. 26).

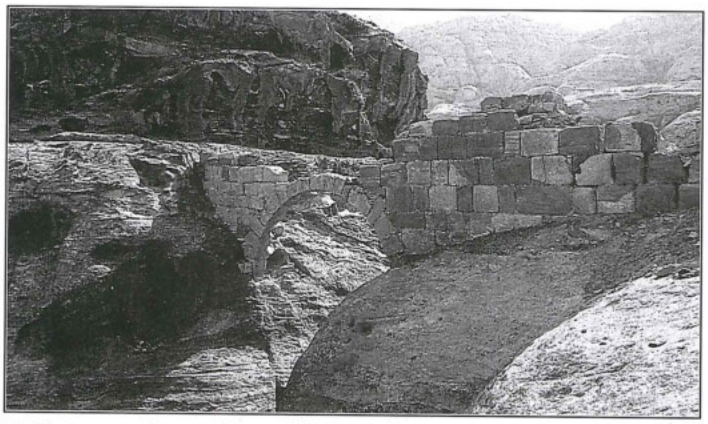
30 There is a discussion of conduit blocks in Oleson and Eadie (above, n. 18) 69-70; see also Oleson (above, n. 18) 1987, 1988, 1991.

31 *Ibid.*

32 Aqua Marcia: D. R. Blackman, 'The Volume of Water Delivered by the Four Great Aqueducts of Rome.' *Papers of the British School at Rome* 46 (1978) 52-72; Petra: al-Muheisen (above, n. 10); Ḥumayma: Oleson and Eadie (above, n. 18) 68-69.

33 Yotvata: Evenari *et al.* (above, n. 4) 173-178. Qaṣr al-Mushāsh: G. King, 'Qasr el-Mushash.' Pp. 391-96 in Homès-Fredericq and Hennessy (above, n. 18). Udhruḥ: A. Killick, *Udruh. Caravan City and Desert Oasis.* Romsey, 1987. See also Graf (above, n. 17) 137 on possible Achaemenid *qanawāt* in the Ḥijāz. On *qanawāt* in general, see P. W. English, 'The Origin and Spread of Qanats in the Old World.' *Proceedings of the American Philological Society* 112 (1968) 170-181; H. Gablot, *Les Qanats: une technique d'aquisition de l'eau.* Paris: Mouton, 1979, and on their use in modern Oman, J. C. Wilkinson, *Water and Tribal Settlement in South-East Arabia.* Oxford: Oxford University Press, 1977.

34 See Oleson (above, n. 18) 1987.



11. Petra aqueduct arch over Wādī al-Wu'ayra (Photo: Oleson).

rapidly until they blocked the channel with a mass of worm-like concretions–like a pot too small for a load of vermicelli. Aqueducts are expensive and difficult to build, require constant observation and maintenance, and are easily disrupted. It is no wonder that the settlement of ancient Auara was built around two public cisterns filled by runoff water, and that smaller cisterns of the same type were built beneath private homes even after the construction of the aqueduct system and the reservoir it fed. To Nabataean eyes, harvesting desert precipitation was a more dependable form of water-supply than reliance on a long, spring-fed conduit. The same pattern can be seen even at Petra, which was served by a shorter conduit fed by a far more generous spring.

Because of their smaller scale, Nabataean aqueducts were more flexible in their design requirements than Roman aqueducts, but they still had to cope with a ground-level course in landscapes that were often very highly dissected. Nabataean engineers dealt with the resulting problems by the use of heavy support walls, viaduct bridges–seldom more than a metre or two high, but not infrequently 10 or 20 metres long–slab bridges over small gulleys, channels cut in cliff faces, and in a famous instance at Petra, an arched bridge over the deep, narrow Wādī al-Wu'ayra (FIG. 11).[35] Although some Nabataean conduits incorporated terracotta pipelines for part of their course–notably in the Sīq at Petra–I am not aware of any documented examples of intentionally pressurized systems used as inverted siphons to carry water across a significant depression without the use of a wall or arch. Such inverted siphons were prominent features of many Hellenistic and Roman water systems, as close by as Jerusalem and the Jordan Valley.[36] Because the capacity of their conduits was relatively small, Nabataean hydraulic engineers could lay out channels down slopes that were unthinkable to Roman engineers, and could build into the system sharp bends and sudden changes in level. Vitruvius proposes a slope of 0.5 percent as appropriate for an aqueduct channel, and surviving Hellenistic and Roman aqueducts typically have slopes between 2.0 and 0.03 percent.[37] The overall slope of the aqueduct leading to Ḥumayma is 2.5 percent, but at points where the channel descends the ash-Sharāh escarpment, the channel slope varies from an impressive 10 to an astonishing 50 percent.

It is interesting that Auara reached out farther into the countryside for its water than any other Nabataean settlement and at the same time made use of a full array of the other more typical Nabataean water-harvesting techniques. Although the technology is typically Nabataean, the scale of the Ḥumayma aqueduct may reflect a familiarity on the part of King Aretas III (who was given the epithet "Philhellene") with Hellenistic and Roman aqueduct systems in the eastern Mediterranean. To be sure, there was marked Hellenistic influence on the design of the typical Nabataean cistern (see below).

Just as their resources were smaller, Nabataean applications of running water were fewer, and the physical arrangements for distribution correspondingly less elaborate than those for a Roman metropolis. Instead of being divided up into pressurized pipelines serving public fountains, public baths, and private homes–as Vitruvius recommends (8.6.1-2)–the water splashed quietly into public reservoirs to which access was arranged by Nabataean tribal custom and probably sanctioned by religion, sometimes visibly, in the form of Dhushara blocks representing a major Nabataean deity.[38] The overflow from the primary storage tanks probably was conducted into private cisterns and small agricultural plots in accordance with similar arrangements. At Ḥumayma, the aqueduct, built soon after the settlement's foundation, was designed to fill a large, shallow reservoir with a capacity of 633 cubic metres, located on a rise 300 metres northeast of the settlement centre (FIG. 12). It is likely that this water was intended to support the needs of transient groups that pitched their tents on the flat ground around the reservoir when agricultural, pastoral, or commercial activities brought them to Auara. King Aretas,

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35 The Petra arch is illustrated in A. Kennedy, *Petra*. London: Country Life, 1925, FIG. 188; A. Musil, *Arabia Petraea*, II: *Edom*. Vol. I. Vienna: Hölder, 1907, p. 58, FIGS. 20-21. A very Roman-looking arch supports a Nabataean type aqueduct serving a site at as-Sādah, near Petra: M. Lindner, S. Farajat and J. P. Zeitler, 'Es-Sadeh: An Important Edomite-Nabataean Site in Southern Jordan.' *ADAJ* 32 (1988) 75-99.

36 For Jerusalem, see J. C. Wilkinson, 'Ancient Jerusalem. Its Water Supply and Population.' *PEQ* 106 (1974) 33-51. There were many cut stone pipeline siphons serving fortresses in the region of Jericho; see G. Garbrecht and J. Peleg, 'Die Wasserversörgung geschichtlicher Wüstenfestungen am Jordantal.' *Antike Welt* 20.2 (1989) 2-20. On the technology of Roman siphons in general, see A. T. Hodge, *Roman Aqueducts and Water Supply*. London: Duckworth, 1992, pp. 147-160.

37 Vitruvius 8.6.1; see now Hodge (above, n. 36) 347-348, and *passim*.

38 There are Dhushara images at several of the cistens around Ḥumayma, and a large Dhushara block adjacent to the stairs giving access to the pool formed by the dam south of the city; Oleson (above, n. 27) FIG. 4. On the religious overtones of water-supply systems in the ancient Near East, see J. P. Oleson, 'Water Works.' *Anchor Bible Dictionary* 6 (1992) 883-893.

12. Reservoir at end of aqueduct, Ḥumayma (Photo: W. and E. Myers).

the founder, may have intended this reservoir, like the more conventional cisterns in the settlement centre below, to serve as an impetus to sedentarization. In its original state, the reservoir channeled overflow water into a covered conduit that carried it towards the settlement centre, possibly to fill smaller private cisterns, or more likely to serve small orchards and vegetable gardens south of the settlement. Unfortunately, this section has now been completely lost.

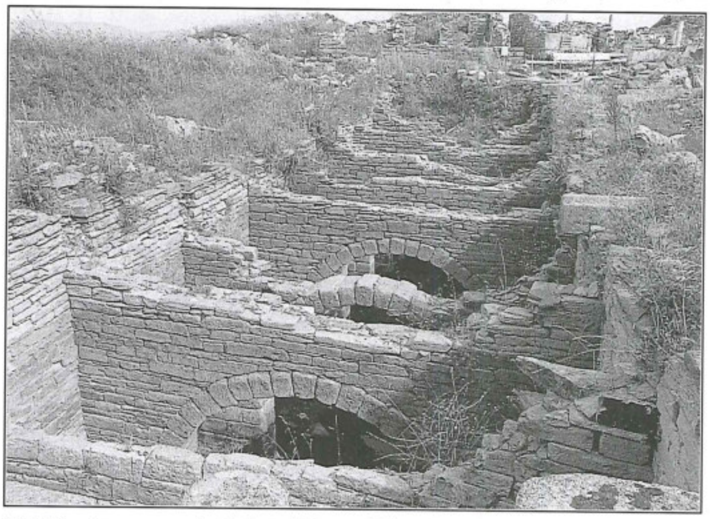
Although Nabataean reservoirs such as the one at Ḥumayma can hold significant amounts of water, Nabataean engineers did not have the means to roof them.[39] The water in the Ḥumayma reservoir was constantly renewed by the flow of the aqueduct, but dead-end reservoirs in this region, fed only occasionally by runoff, must have involved significant problems. In the absence of a roof, evaporation would have claimed up to four metres of water every year, and exposure to the sun would have fostered the proliferation of plant and animal life that rapidly spoiled the quality of the water. In addition, pollutants are more easily introduced into un-roofed cisterns, and animals and people can fall in. It may be that large, unroofed, dead-end reservoirs were used only to water animals, or that the water was carried by porters to

39 For other early reservoirs, see the citations in Oleson and Eadie (above, n. 18) 61.

fill domestic tanks and cisterns soon after it was captured.[40] The typical Nabataean arrangement for long-term storage of still water was very different. The bottle-shaped cistern cut into bedrock, mentioned above in the passage by Diodorus, was in use in Edom by the Iron Age, and it was part of the secret of the early Nabataean success in taming the desert.[41] Such cisterns were relatively easy to plan and excavate, but they had the important drawback that they had to be located where suitable bedrock was available in conjunction with an appropriate runoff field. Since Nabataean stonemasons were producing beautifully trimmed ashlar blocks for the construction of substantial buildings from at least the second century BC, cisterns obviously could have been built where they were needed using the same sort of blocks, and waterproofed with the same kind of plaster used for the rock-cut cisterns. Roofing, however, was the problem, particularly since the friable sandstone used for so much Nabataean architecture could not bridge any significant span and timber was unavailable. The solution ultimately adopted was to span the cistern with transverse arches, the squinches of which were levelled off with filler blocks to support roofing slabs (see FIG. 5). The use of this design allowed the construction of cisterns wherever the water they could contain was needed, and wherever the catchment area was most suitable, regardless of the local geology. King Aretas III, for example, was free to select as the site of Auara a location appropriate all at once for water harvesting, agriculture, housing construction, campground and land communications. The two public cisterns were built just to one side of the focus of a catchment of a size obviously more than sufficient to supply them, but at the same time not so large or so steep as to constitute a danger to nearby structures. The cisterns were roofed with 16 arches, carrying a roof of heavy stone slabs well chinked and sealed with mortar, so that people and goats could move around and over them without hazard to themselves or the precious water within.

This cistern design quickly became typical of virtually every Nabataean site, and the method of roofing was soon applied to the stone houses of which the newly sedentarized Nabataeans became so proud.[42] Cisterns and houses continued to be roofed in this manner throughout the area of the former Nabataean kingdom until the early Islamic period. The Nabataeans seem to have discovered through experiment that a span of six to seven metres was the maximum that could reliably be roofed by this method, and that depths greater than five or six metres were inconvenient, unnecessary, or structurally difficult.[43] As a result, cisterns that had to be large in capacity were built on a rectangular plan, seven metres wide and as long as necessary to provide the desired capacity. The design was applied to rock-cut cisterns as well. Cisterns beneath the private homes at Auara, in contrast, tended to be round, with a maximum diameter of five or six metres, and depth of around five metres (FIG. 6). The circular plan may represent the tradition of Iron Age bottle cisterns, but it is also more economical of material, easier to build and plaster, and more resistant to the compression of the surrounding soil than square or rectangular plans. All of these cisterns had relatively long, block-built intake channels incorporating a small, rectangular settling tank, usually with arch-supported roof. These tanks allowed at least some of the debris carried by the rapid runoff to settle out before the water spilled over into the main tank.

Unfortunately, because of the lack of excavation and problems in dating Nabataean ceramics, the chronology of the spread of this useful design is still not known. The ceramic evidence uncovered so far at Ḥumayma suggests strongly that the two public cisterns there were built at the time of the settlement's foundation in the 80s BC. The design, however, had appeared in exactly comparable form in the Hellenistic world by at least the third century BC. Such cisterns can be seen at arid, treeless sites such as Delos, where a particularly large one appears next to the theatre, although others can be found throughout the site (FIG. 13). The design of the cistern of the Nekromanteion at Ephyra is also similar. The same roof design also occurs in Hellenistic military and temple



13. Theatre reservoir, Delos (Photo: Oleson).

40 See Oleson (above, n. 38) for literary sources concerning these practices.

41 For bottle cisterns, see above, n. 14.

42 Strabo 16.4.26. A good example of a stone house of Strabo's period has been excavated at Petra: see R. A. Stucky *et al.*, 'Schweizer Ausgrabungen in es-Zantur, Petra.' *ADAJ* 34 (1990) 249-283. Although restored over a long period, the houses at Mampsis are Nabataean in origin: see Negev (above, n. 26) *passim*.

43 It is very difficult to date these cisterns, which generally remained in use for centuries. The statistics on dimensions are based on measurements taken by Oleson from cisterns associated with possibly Nabataean contexts in Jordan and southern Palestine.

architecture where rooms must be placed beneath a heavy paving, as in the Temple of Apollo at Claros.[44]

The question of the means by which this design was brought back to Nabataea, and spread throughout the small scattered settlements and the arid landscape around them is tantalizing. Alexander the Great's army is felt to have played some role in bringing back the knowledge of the arch and vault from Mesopotamia to Macedonia, and military engineers seem to have been involved in the further spread of the technology of vaulting.[45] From the late fourth century BC until the arrival of Pompey, the Nabataean kingdom bordered on Greek-ruled or Hellenized states on all but its east and southeast borders, and there is ample evidence for the activity of Greek armies in and around the kingdom during the appropriate period. Nabataean officers or engineers might well have learned the design from Greek allies, or from the inspection of abandoned or captured Greek outposts or settlements. Josephus describes the travels of Syllaios and other Nabataean officials around the Mediterranean (e.g. *AJ* bk. 16), and Nabataean officials (and soldiers) must have seen a number of Hellenistic capitals around the Aegean. In addition, Nabataean merchants were active on both the Red Sea and the Mediterranean by at least the first century BC. Inscriptions in Aramaic or in Aramaic and Greek set up by Nabataeans, or in Greek relating to Nabataeans, have been found in Egypt, at Sidon, Cos, Rhodes, Delos, Puteoli, Ostia and Rome.[46] The character of the sites where Nabataean inscriptions have been found suggests commercial interests. At Delos, for example, Nabataean merchants could have seen this type of cistern in operation and easily have comprehended the splendidly simple principles of the design and its appropriateness to conditions in the Nabataean lands. It is also possible, although ultimately probably impossible to document, that the Nabataeans noticed the roofing design in the context of military structures rather than cisterns, and brought it home to facilitate the construction of dwellings. In view of the remarkable similarity of design linking Nabataean and Hellenistic cisterns, however, and given the critical importance of water supply to Nabataean survival, it seems more likely that the cistern application was primary.

However the design for the arch-supported roof arrived, it must immediately have helped foster the growth of Nabataean settlements and the sedentarization of their culture. Once cisterns with stable roofs could be built wherever they were needed rather than cut in bed-rock, the Nabataeans were freed from their previous dependence on rocky outcroppings and the hazardous runoff fields associated with them. They could then settle sites such as Auara, arranging for runoff water supplies close to routes of travel and agricultural land. The built, arched roof was also applied to rock-cut cisterns, since it facilitated excavation and maintenance of the tanks, and concealment was not a major concern after sedentarization of the Nabataeans.

Although our research at Ḥumayma is still in progress, we can now discuss it as an excellent, well preserved and well documented example of all the aspects of Nabataean hydraulic technology. The archaeological research must now be supplemented by literary and ethnographic evidence in an attempt to reconstruct the patterns of water use and social context of distribution and consumption. The provision of both fresh and cistern water must have been a source of great satisfaction to the inhabitants of Auara and the neighbouring desert. They probably preferred to drink fresh spring water rather than cistern water whenever possible, but the procedures for arranging access and sharing of this portion of the water supply can no longer be documented directly. There must also have been some method of ensuring the equitable division of the runoff water in the public cisterns. The water in private cisterns then, as today, must have been private property. In a related matter, there must have been some social control over catchment fields.[47] Certainly the catchment field for the public cisterns at Ḥumayma seems to have been protected from extensive construction throughout Auara's history. There must also have been some method of social control over the appropriation of catchment fields for private cisterns. The water supplies in the settlement centre would have sustained the populace and the animals kept in the town, and would also have been used for washing, and for craft processes such as pottery production or fulling. Any excess, particularly overflow from the reservoir, may have been directed to the irrigation of small plots of vegetables or fruit trees in the immediate downhill vicinity of the settlement. This is the practice today near the springs.

The fields of wheat and barley, however, which probably spread out over thousands of hectares around Auara as they do today, were irrigated naturally by direct winter rainfall and, to a much greater extent, by run-off from adjacent slopes or the great wadis themselves, which brought down the water of the ash-Sharāh escarpment.

[44] R. Vallois, *L'architecture hellénique et hellénistique à Délos*. Paris: de Boccard, 1966, pp. 264-279. For early Greek arches and vaults, see T. D. Boyd, 'The Arch and Vault in Greek Architecture.' *AJA* 82 (1978) 83-100; S. Miller, 'Macedonian Tombs: Their Architecture and Architectural Decoration.' Pp. 153-171 in B. Barr-Sharrar and E. Borza, *Macedonia and Greece in Late Classical and Early Hellenistic Times.* Washington D.C.: National Gallery, 1982; R. A. Tomlinson, 'The Architectural Context of the Macedonian Vaulted Tombs,' *Annual of the British School of Archaeology in Athens* 82 (1987) 305-312.

[45] See references in note 44, esp. Tomlinson.

[46] A summary of the location and publications of these inscriptions can be found in R. Wenning, *Die Nabatäer—Denkmäler und Geschichte.* Göttingen: Vandenhoeck und Ruprecht, 1987, pp. 22-25.

[47] Compare the situation at Shivta, Y. Kedar, 'Ancient Agriculture at Shivta in the Negev,' *IEJ* 7 (1957) 178-189.

As today, farmers probably owned specific fields that they would plant in the winter after observing which had received sufficient moisture to nurture a crop.

On the whole, this arrangement must have lasted basically unchanged for as long as Auara did. Sometime during the Roman period, probably in the second or third centuries AD, a new reservoir was provided on the ridge, inside the protective walls of a new military camp. Although this reservoir diverted only part of the water brought by the aqueduct, it represents confiscation of the greater portion of the highest-quality source of water for the settlement. Such total reliance on aqueduct rather than runoff water is typically Roman, expressive of a confidence in complex, highly artificial systems of water management and in long-term political stability. This same self-confidence is represented by the provision of a bath building for Auara during the late Roman period, with the typical radiant heating in the floors and walls.[48] The stopcock installed in the Nabataean reservoir to replace the previously uncontrolled outflow, and the pipeline laid in the outflow conduit, are also typically Roman. Together with the enclosed castrum reservoir, they seem to represent both new applications of the water and new restrictions on its consumption. The replacement of an unrestricted overflow conduit with a locked, valved pipeline can be seen as a technological metaphor for the way in which Roman law, which had evolved to serve the needs of a developed, cosmopolitan empire, replaced the rigid but unwritten, informal laws of the desert tribes.[49] Here again we see outside influence on Nabataean hydrualic technology, but this time more vivid and easier to appreciate. Nevertheless, it was still essentially a veneer on a native, Nabataean system, as the ultimate history of the site shows.

We do not as yet know precisely when the aqueduct stopped bringing water to Auara, because the settlement proper probably could have survived on runoff sources alone. Umayyad potsherds do, however, appear in significant numbers around the Nabataean reservoir, and in the fill of the castrum reservoir, so one or both of these structures probably held water into the Islamic period; the aqueduct is the only method of filling them. In addition, a round cistern with domed roof in the settlement area may be an Umayyad construction. It is a testimony to the essential reliability of the indigenous runoff system that most of the ancient cisterns in the Auara catchment still fulfill their original purpose after only minimal renovation, while the aqueduct, and the reservoirs it served, are dry.

48 See Oleson (above, n. 18) 1990.

49 On Roman water administration, see W. Eck, 'Die Wasserversorgung im römischen Reich: Sozio-politische Bedingungen, Recht und Administration.' Pp. 49-102 in G. Garbrecht, ed., *Die Wasserversorgung antiker Städte*. Mainz: von Zabern, 1987. On tribal administration, see Wilkinson (above, n. 33); *idem*, 'Islamic Water Law with Special Reference to Oasis Settlement.' *Journal of Arid Environment* 1 (1978) 87-96; Trousset (above, n. 26).